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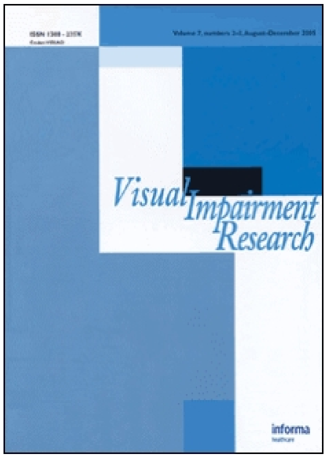

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ABSTRACT *Background*: In Europe, driving a passenger car is prohibited if binocular best corrected visual acuity (BCVA) is below 0.5 (20/40). Some US states allow people with reduced visual acuity to use a bioptic telescope system when driving. The aim of our study is to introduce a bioptic telescope system for driving in the Netherlands and to investigate whether it enables people with reduced visual acuity to gain sufficient practical fitness to drive in a European setting. *Results*: Out of 378 persons who applied for information following media attention for the project, 160 candidates volunteered to participate. Based on the available information, 36 subjects (binocular BCVA: 0.16–0.5 [20/125–20/40]) were invited for assessment (vision, mobility, cognitive function, and driving skills). Of these, 16 did not meet the inclusion criteria and 2 decided not to participate. The remaining 18 subjects were trained in the use of a monocular bioptic telescope (3× magnification). They all completed the predriving training successfully and received driving lessons from specialized professional driving instructors. Eventually, 9 subjects passed the official on-road test of practical fitness to drive, 7 were excluded after a number of driving lessons, and another 2 withdrew on their own initiative. *Conclusion*: This is the first study in Europe to prepare subjects with reduced visual acuity to drive with the use of a bioptic telescope system. About 55% of the preselected subjects fulfilled all inclusion criteria. Half of the subjects who entered the bioptic training program passed the official fitness to drive test, demonstrating that they could drive smoothly and safely in Dutch traffic using a bioptic telescope system.

KEYWORDS Vision rehabilitation; fitness to drive; optics; orientation and mobility training; Europe

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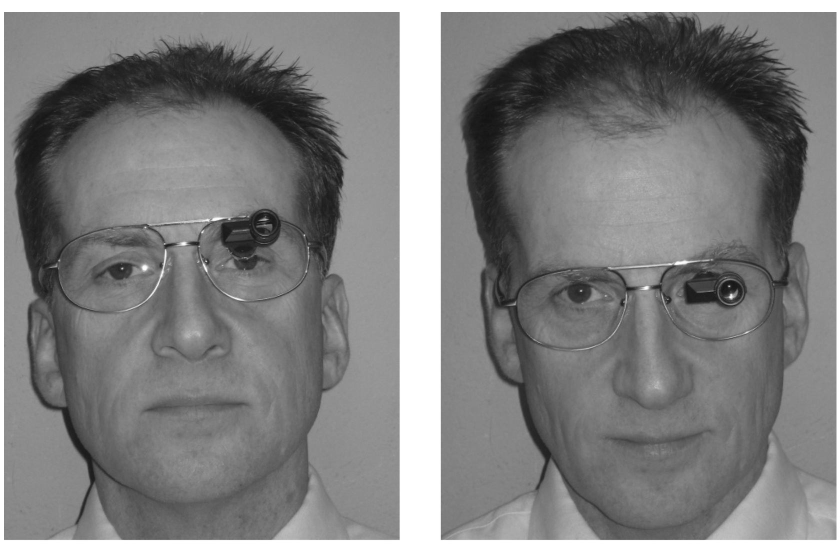
INTODUCTION

Without a doubt, vision is crucial for the complex task of driving a motor vehicle and constitutes the main input of information to the driver. Reduction of visual function can limit the ability to drive a car safely and, for this reason, official minimum requirements regarding the visual capacity of drivers are set by legislative authorities. On the other hand, the ability to drive independently is very important for social as well as economic reasons[1–4] and such a major privilege should not be denied unjustly.

The exact limit of visual acuity for safe driving is difficult to determine. In the member countries of the European Union (EU), driving a passenger car is currently not allowed for drivers with binocular best corrected visual acuity (BCVA) of worse than 0.5 (20/40).[5] However, this limiting value is not evidence based and seems rather arbitrary. Several previous studies showed only weak relationships between visual acuity and practical fitness to drive or driving safety.[6–12] In the study of Coeckelbergh et al,[13] 25% of the subjects with corrected binocular visual acuity in the range 0.1–0.5 (20/200–20/40) passed the official on-road test of practical fitness to drive, demonstrating that they could drive safely and smoothly in normal traffic. Visual acuity correlated significantly with the final driving test score, but accounted for only 20% of the variance in the pass/fail score of the practical fitness to drive test.[7,14] Furthermore, in a number of US states,[12,15,16] the threshold acuity required for driving without restrictions lies below the European standard and this does not generally lead to more accidents.[17] Although a visual acuity below the limiting value of 0.5 (20/40) is a clear indication of impaired vision and needs closer inspection, these results cast doubt on the use of this limit as an automatic exclusion criterion for driving. Korb[18] and Feinbloom[19] already recognized the potential for a bioptic telescope system (BTS or bioptic), which is the combination of a small telescope (typically 2×–4×) mounted in the upper part of a carrier lens that is made to the individual's refractive prescription, to be used for driving (see Figure 1). This optical aid allows rapid fixation changes between viewing through the carrier lens and through the telescope by a slight nod of the head (typically vertically about 15–20 degrees). It enables the driver to survey general traffic through the normal spectacle carrier lens for most of the time (see Figure 1A), and to use the telescope briefly for spotting tasks such as reading a traffic sign or looking far ahead to survey an approaching intersection (see Figure 1B). A monocular bioptic telescope allows a driver with moderate central vision impairment but good peripheral vision to increase visual acuity instantly without losing the overall view. A brief glance through the telescope enables bioptic drivers to gain detailed information from, for instance, road signs and distant objects, which they are unable to see in time without magnification. In contrast to the EU where low vision driving with a bioptic is not allowed, it is permitted in 36 US states,[15,16,20] where there are more than 4000 bioptic drivers.[21] However, because of differences in, for instance, standards of driving, traffic density, and road design, it is not a priori evident that bioptic driving would also be a feasible option in Europe. Defining a solid protocol for bioptic driving based on local



(A) (B)

FIGURE 1 **Bioptic telescope system. (A) Bioptic position while looking ahead through carrier lens. (B) Bioptic position while looking through telescope. (Photos by P.H. Derksen, Holsboer Optometrie, Arnhem, The Netherlands.)**

legislation, and reproducing some of the promising results achieved in the United States in a Dutch setting, are considered to be the first steps towards legalization for bioptic driving in the Netherlands. From this point of view, Royal Visio, National Foundation for the Visually Impaired and Blind, planned the demonstration project *AutO* & *Mobiliteit*.

As no practical expertise on the subject of bioptic driving was available in the Netherlands, we thoroughly reviewed the existing scientific literature (Melis-Dankers, Kooijman, Brouwer, Wieselmann, and Witvliet, this issue). There were no serious objections to starting an explorative demonstration project on bioptic driving in the Netherlands. Visio joined forces with scientific and public institutes, specialist driving schools, and the official Netherlands Bureau of Driving Skills Certificates (CBR). The process of introducing bioptic driving in the Netherlands and acquiring the necessary knowledge and experience is described in detail by Kooijman and coworkers (this issue). Based on our review of the scientific literature and expert information, we generated an interdisciplinary assessment and training protocol for bioptic driving. This paper describes our protocol and the data of the demonstration project *AutO* & *Mobiliteit*. It is important to note that none of the subjects could obtain the legal right to drive by participating in our project, simply because bioptic driving is not allowed in the Netherlands.

Since this is the first publication of a practical bioptic driving project outside the United States, it might be of interest to organizations in other countries who may be considering the adaptation of driving licence regulations to increase the mobility options for the growing population with moderate visual impairments. In the meantime, several European research groups have shown an interest in the topic, and a German consortium has already started to study bioptic driving (PRIAMOS, Project Initiative zur Auto-Mobilität von Menschen mit Seheinschränkungen, Düren, Germany; personal communication, April 2007).

METHODS

Our protocol is largely based on the current practice in Berkeley California (Professor Ian L. Bailey, optometrist, and Helen Dornbusch, mobility instructor, School of Optometry, University of California, Berkeley, California, USA) and the Schepens Eye Research Institute (Professor Eli Peli, optometrist, Harvard Medical School, Boston, Massachusetts, USA, and René Paquin, MEd, certified orientation and mobility specialist, Crotched Mountain School, Greenfield, New Hampshire, USA), and has been adapted to the situation in the Netherlands.

Setting

The sector Assessment and Rehabilitation of Royal Visio, National Foundation for the Visually Impaired and Blind in the Netherlands, consists of 12 regional institutes which provide visual rehabilitation services to the northern, western, and eastern parts of the Netherlands. About 500 professionals support people who have low vision or who are blind in their goal to live an independent life despite their visual impairment. The services, which are delivered on an extramural basis, include ophthalmologic, sensory and perceptual visual assessments, low vision services, social work, and a wide variety of rehabilitation training. The institutes are mainly financed by the national healthcare insurance system, as a result of which most rehabilitation services are free of charge for low vision clients.

Collaboration and Allocation of Tasks

The project was organized simultaneously at 2 regional institutes of Visio (in Haren and Apeldoorn). Visio was responsible for the general project coordination, the recruitment of subjects, visual as well as neuropsychological assessment, subject counseling, predriving training with a bioptic, and the collection and evaluation of data. The Department of Ophthalmology of the University Medical Center Groningen (UMCG) supervised the scientific embedding of the project and the selection of the subjects (ACK). The Department of Psychology of the University of Groningen and the Department of Neurology of the UMCG were concerned with the monitoring of progress in driving performance in the course of the project (WHB and RBB). Two driving schools, specializing in driving with physically impaired people, performed the driving screening for subject inclusion and gave the driving lessons (Niemeijer, Scheemda for the northern part of the Netherlands; Welzorg, 's-Hertogenbosch for the rest of the country). The CBR (Rijswijk), the official driving licence authority in the Netherlands, was responsible for the final on-road testing of practical fitness to drive. In order to minimize unforeseen problems, a feedback committee consisting of 6 experts (in driving regulation, ophthalmology, low vision rehabilitation, low vision patient network, low vision research, and driving research) operated in the background to advise on issues vital for the success of the project.

Training of Professionals

As no practical experience of driving with bioptics existed in the Netherlands, all professionals involved had to be informed about and trained in all aspects of the procedure. This process is described in detail by Kooijman and colleagues (this issue).

Bioptic

Detailed information on the variety of bioptic devices available and their specific use for driving is provided by Melis-Dankers et al (unpublished data, 2008) and Peli.[22] In this demonstration project we used an Ocutech VES-mini telescope (3 × 8; Ocutech, Chapel Hill, North Carolina, United States, www.ocutech.com; see Figure 1). The main characteristics of this Keplerian system are its small size, its large field of view (14.7°), its high optical quality, and its low weight (17 g). The telescope yields a sharp overall image without color shifting or aberrations. The small exit pupil has to be aligned carefully with the eye pupil. Furthermore, according to the manufacturer's specifications, the telescope provides for refractive error correction (internal by focus +12/−12 diopters) and has a closest near focus of about 23 cm at emmetropic setting. These features allow subjects to use the aid in a wide variety of everyday situations, which was expected to have a positive effect on the use of the bioptic while driving. The use of only one type of telescope for all subjects allowed easy disassembly and reuse of the telescopes.

The telescope was fitted monocularly, allowing the driver to improve visual acuity with 1 eye whilst preserving the overall field of view with the other eye. During the assessment phase, clip-on telescopes were available which could be attached to any pair of glasses to give an impression of the use of a bioptic and to test the general visual performance of the candidates. Distant visual acuity through the clip-on telescope had to be 0.5 (20/40) or better to continue participation in the project. After passing the assessment phase, a permanent bioptic was fitted individually by the low vision specialist.[23,24] The monocular telescope was mounted in the upper part of the carrier lens of either the best or the dominant eye, depending on the subject's preference.

Subject Recruitment

A complete overview of the inclusion and exclusion criteria is shown in Table 1. These criteria were largely based on national legal regulations[5,25] and our literature

TABLE 1 **Inclusion and exclusion criteria**

Inclusion criteria
- Binocular BCVA without bioptic: (Lighthouse ETDRS 2000 chart at 4 m and 500 lux) 0.16–0.50 (20/125–20/40)
- Monocular BCVA with telescope 0.5 (20/40) or better
- Ophthalmologic situation stable for at least 1 year
- Binocular horizontal field of view ≥140° (Goldmann III-4e)
- Peak log contrast sensitivity within normal limits (Vistech VCTS6500 ≥ 1.6 at 3–6 cycles/degree [B5 or C4])

Exclusion criteria
- Only 1 functional eye
- Peripheral visual field defect (Goldmann)
- Absolute central scotoma (Goldmann + Amsler test)
- Diplopia (without telescope)
- Significant metamorphopsia (Amsler test at 30 cm and 1000 lux)
- Cerebral vascular accident
- Posttraumatic amnesia >1 week
- Coma >1 day
- Possible signs of dementia, attention, or memory disorders
  - Trail Making Test A + B (A, B, and/or B/A below 10th percentile)
  - Mini Mental State Examination (MMSE; only used for subjects > 65 years, MMSE < 25)
- Psychiatric treatment within the past 5 years
- Hearing impairment
- Problems with balance or orientation

review (Melis-Dankers et al., this issue). Candidates were continually recruited between May 1, 2004, and April 30, 2006, through publicity about the project in national and regional newspapers and among regular clients of Visio. Over this 2-year period, 378 people applied voluntarily for participation or additional information. All applicants were contacted, mostly by telephone, which revealed that 135 of them did not fulfill the inclusion criteria or were not interested in further participation because of the expenses and efforts attached to participation and the uncertainty of whether bioptic driving would be legally permitted in the Netherlands in the near future. The remaining 243 candidates received additional information about the project. Special attention was paid to their motives for participating, the general risks related to driving with low vision, possible alternative forms of transportation, and the financial costs of participation for the subjects. Assessments, additional travelling expenses, and the predriving training were paid for by Visio and the on-road test of practical fitness to drive was free of charge for the subjects as well, but the costs of the individual driving lessons and the bioptic device had to be paid for by the subjects themselves. On the basis of the information provided, 218 candidates agreed to receive a printed questionnaire with questions related to the inclusion criteria and detailed written information about the project. In total, 160 questionnaires were returned (73%). The total number of subjects to be included in the demonstration project was not determined beforehand. We estimated that at least 8 to 10 bioptic drivers had to pass the official on-road test of practical fitness to drive in order to start the procedures that might lead to legalization of bioptic driving in the Netherlands. Based on the expert information provided and our literature review, we tried to select the candidates who were most likely to pass the fitness to drive test without requiring a large number of driving lessons. Of the candidates who returned the questionnaire, 75 candidates were preselected on the basis of the information they had provided about their general medical history, their ophthalmic disorder and its stability, their motivation for participating, visual acuity, and visual field. If needed, detailed recent ophthalmologic information about candidates was requested from their own ophthalmologists. At the beginning of the project, we included equal numbers of new and experienced drivers. Because it soon appeared that new drivers needed a substantial number of lessons to attain the minimum level of driving skills required for the assessment of practical fitness to drive, we subsequently tended to prefer older and experienced drivers. Based on the information about the candidates, we selected 36 subjects during the 2-year period: 26 males and 10 females, between the ages of 18 and 81 (median = 38, first quartile = 28, third quartile = 56). These 36 subjects were invited to one of the 2 participating institutes of Visio for an assessment day (25 in Apeldoorn and 11 in Haren).

The first selection of candidates was made prior to the assessment day on the basis of visual acuity, visual field, and the ophthalmic disorder and its stability, as provided by the candidate or their ophthalmologist. The selected 36 subjects were tested for all inclusion and exclusion criteria during the assessment day. The visual performance with a bioptic was measured with a clip-on model on the assessment day.

Inclusion Assessment

The assessment day started with a low vision assessment by a low vision specialist (Table 1). Subjects who fulfilled all optometric inclusion criteria proceeded to an informational interview with 1 of the client counselors. During this interview, the questions of the subject were answered, and the project details, driving history, and motivation for participation were discussed on the basis of a questionnaire.

Next, an orientation and mobility (O&M) trainer observed the subject's viewing behavior in a number of daily mobility situations, with and without a clip-on telescope. The subjects had to demonstrate attentive viewing behavior in everyday traffic situations comparable to normal pedestrians. During this mobility test, the trainers also checked for balance or orientation disorders.

To exclude subjects with dementia and learning, attention, or memory disorders, a neuropsychological test battery consisting of the Trail Making Test versions A and B,[26,27] and the Mini Mental State Examination (MMSE)[28] were administered by a psychologist.

Initially, the assessment day did not include a behind-the-wheel screening test for driving. From the 16th subject onwards, we introduced a preliminary screening test for driving on the assessment day to avoid high expenses of driving lessons in cases where general driving skill was low. In this test, one of the driving instructors judged the driving experience and viewing behavior of the subject in regular traffic without a bioptic. The last

21 subjects were only included in the project if the driving instructor was satisfied with their aptitude to drive. The assessment day ended with a concluding conversation with the client counselor during which remaining questions of the subject were answered. Subjects had to sign an informed consent form. All assessment results were evaluated by both clinical physicists (A. C. K. and B. J. M.), who decided whether to admit the subjects to the subsequent training program. Only after admission, a customized bioptic telescope system was fitted by the low vision specialist.

Predriving Training

By far the most important factor to be learned with regard to the bioptic is that the telescope is used only very briefly and at specific moments. Almost all driving is done while looking through the carrier lens. The telescope is used only as an aid to inspect details and to spot distant objects briefly, allowing better anticipation of traffic situations ahead. Prolonged searching through the telescope must be avoided. The bioptic telescope spotting action can be compared with the way a regular driver glances into the rearview mirror. Secondly, the bioptic driver has to become accustomed to integrating the enlarged monocular image of the telescope into the complete visual field. Alertness to changes in the periphery while glancing through the telescope is assumed to be an advantage. As the view through the telescope must not last longer than about a second, the combined eye and head movement has to be goal directed and perfectly timed. In addition, one has to get used to objects and movements appearing to be larger and closer when seen through a telescope. Practice in using the system in a smooth and coordinated manner is necessary to obtain continuous visual perception and to prevent the subject from becoming disoriented.

To develop the proficient use of the bioptic, 4 individual weekly training sessions of 3 hours each were given by one of the O&M instructors. The subjects learned to use the customized bioptic correctly in everyday situations (except behind-the-wheel driving). Subjects had to practice using the bioptic on the days between the weekly training sessions (homework), and to keep a diary about frequency, location, and duration of practice and weather conditions. If possible, they also practiced locating and recognizing signs as a passenger in a car driven by a family member or acquaintance. Each training session started by checking that the subject had mastered the goals of the previous training sessions and ended with an evaluation of the session and an explanation of the homework.

Training Session 1

The goals of the first training session were that the subjects were able to spot and recognize pictures, and read some words through the telescope. They first had to spot stationary objects whilst standing indoors. The subjects were instructed to make the appropriate head and eye movements and to decrease the duration of spotting. The exercises included the recognition of different pictures and symbols on a wall, as well as reading words (direction signs), and instant selection of relevant information. If successful, instruction continued with moving objects. They also had to perform viewing tasks outdoors standing beside a road.

Training Session 2

The goal of this session was to increase viewing speed. The subjects had to read cards held up for a short duration by the instructor. In addition, the subjects learned to spot stationary and moving objects while walking. They were instructed to spot through the telescope at the right moment for only a second or less. Several slides with pictures of traffic signs were used. Most of the traffic signs were recognized by looking through the carrier lenses, but sometimes the use of the telescope was necessary to identify certain details. A comparable exercise was carried out in normal traffic situations while walking outside. The subjects also practiced the use of their bioptic while being driven around as a passenger in a car on highways and quiet roads. They had to detect signs along the road through the carrier lenses and to decide whether it was necessary to look through the telescope to see more details. They were instructed to use the telescope at the right moment. If they spotted too early they were not able to read the sign, and if they spotted too late there was not enough time to respond properly. The subjects also visited a large department store or do-it-yourself shop where they had to perform various viewing tasks in a cluttered visual environment. Here they could experience how the bioptic could also be used for other tasks and at various distances.

Training Session 3

During this session, the exercises were aimed at the correct judgement of traffic situations and developing the habit of anticipating and looking ahead. The subjects had to scan quickly projected slides of traffic situations through the carrier glasses and use their telescope to inspect the sites with important information in more detail. As a passenger they learned to look ahead to judge each situation in time and to select the important visual information. Road signs had to be recognized and read. Subsequently, the subjects had to navigate independently by finding a route to an arbitrary chosen destination, reading road signs and giving directions to the driver. Meanwhile, they had to report verbally on the presence of other road users and on important information such as speed limits and stop signs.

Training Session 4

In addition to a repetition of previous exercises, the use of the bioptic was practiced in combination with the car's mirrors. As passengers, the subjects "drove" various routes in complex and heavy traffic situations while carrying out traffic-related viewing tasks with their bioptics.

At the end of the fourth session, the overall viewing behavior with the bioptic was evaluated and it was decided whether the subject could progress to the driving training. The subjects had to master all the described viewing exercises with their bioptic without exception. If the O&M instructor deemed it necessary, a fifth predriving training session was organized.

Driving Training

The driving lessons were given in a regular learner car with automatic transmission by one of the 2 driving instructors, both specialized in driving with physically impaired people, in either the city of Groningen or 's-Hertogenbosch. Each week, two 1-hour driving lessons were given with a short intermediate break. The subjects were instructed to adjust the telescope to infinity each time they took their place behind the wheel. The driving instructors trained the drivers to navigate independently through traffic, to drive safely and smoothly, and to perceive essential information in time to react adequately.

To monitor driving performance in the course of the lessons, the structured protocol of the Test Ride for Investigating Practical fitness to drive (TRIP)[29–32] was used. This test assesses whether the driver demonstrates sufficient general driving skills and compensates adequately for the visual impairment. The standard TRIP protocol was extended to include a number of items to assess the use of the bioptic. The protocol used contained 64 different items in 11 categories, each scored on a 3-point scale ("sufficient," "doubtful," "insufficient"), evaluating specific driving skills and behavior (e.g., position on the road, following distance, speed, and communication with other road users).

At the beginning of our demonstration project, the driving instructors followed their normal routine and only paid special attention to the correct viewing behavior with the telescope when necessary. As they gradually learned that instructions on correct viewing behavior had a positive effect on both viewing and driving performance, they paid more attention to the proper use of the telescope while driving. To limit the subjects' and the project's expenses, the maximum number of driving lessons was originally set at 24. A subject was only allowed more lessons on the strong positive advice of the driving instructor. When the driving instructor was satisfied regarding the driving of the subject according to general standards, the driving of the subject was scored according to the TRIP protocol[31] When the global TRIP scores were "sufficient," the subject was recommended to the CBR for the on-road test of practical fitness to drive.

Practical Fitness to Drive

Practical fitness to drive was examined independently by an official CBR expert on fitness to drive in the same city where the driving lessons had been given. These CBR experts are specialized in the examination of functionally impaired drivers and have been educated regarding medical disorders as related to driving and car modifications. In practice, they use a practice guidance system that guarantees the uniformity and quality of the assessment. The on-road test of practical fitness to drive is defined in the Dutch Regulations for Medical Fitness to Drive.[25] It is considered the golden standard in the Netherlands for determining the practical fitness to drive in people with impairments. It is not a regular driving examination, but a special test drive to determine whether a driver compensates adequately for functional limitations, leading to safe and smooth driving. For our project this implies that, ideally, the visual impairment and the use of the bioptic are not noticeable outside the car. During this one-hour test drive, various aspects were assessed regarding the safety and smoothness of driving while using the bioptic. More detailed situation-related performance was systematically scored with the TRIP-protocol.[29–32] The most important result of the assessment is the global rating of practical fitness to drive. For our demonstration project, we distinguished between "unfit and denied retest," "unfit but allowed retest after additional lessons," and "fit when using the bioptic." The final judgement on the practical fitness to drive was left solely to the CBR expert. Since bioptic driving for people with visual acuity worse than 0.5 (20/40) is not yet allowed in the Netherlands, successful subjects did not obtain a driving licence.

RESULTS

Inclusion Assessment

Sixteen of the 36 subjects (Table 2, subjects 1–16, 44%) were excluded because they did not meet the requirements on 1 or more tests. Two others (subjects 17 and 18) met all the test criteria, but withdrew of their own volition before the start of the predriving training because they were not willing to travel the required distance for the driving lessons and training sessions, and also considered the expenses to be too high.

Despite our precautionary measures, 7 subjects (19%) did not meet our visual acuity criteria, either with or without a telescope. One subject appeared to have a visual acuity without a telescope that was worse than the inclusion threshold of 0.16 (20/125), and 6 others did not reach the required acuity of 0.5 (20/40) with the clip-on telescope for the preferred eye. All of the latter had a visual acuity in the range 0.16–0.20 (20/125–20/100) without a telescope. Two of these 7 subjects could have passed the visual acuity criteria by wearing the telescope on the better, nondominant eye, but they opted not to do this.

Five subjects (14%) had a significant loss of peak contrast sensitivity, and 2 subjects (6%) did not meet our visual field criteria. Seven subjects (19%) scored too low on the basis of the neuropsychological test results, 3 subjects (8%) showed improper viewing behavior with the bioptic during the O&M screening, and 2 (6%) had an unstable ophthalmologic condition. Although the selection of all subjects was based on the information provided by their ophthalmologist, 10 of them (28%) were excluded due to insufficient visual acuity with or without the bioptic, reduced visual field, or unstable ophthalmic condition. The actual driving performance was screened in 12 of the 18 excluded subjects on the assessment day, and 5 of them scored negatively on that test.

Two of the excluded subjects decided on the assessment day to withdraw regardless of the test results, because they anticipated that the training would be too fatiguing and/or the investment in both time and money was considered to be too high (subjects 10 and 16).

Six of the excluded subject held a driving licence. Five of them had extensive driving experience (>50.000 km) in the past. The licences of 7 others had expired. Five subjects never owned a driving licence, but 3 of them had taken driving lessons before.

The remaining 18 subjects proceeded to the predriving training: 14 males and 4 female between the ages of 18 and 72 years (median = 34, first quartile = 26, third quartile = 48 years), 12 in Apeldoorn and 6 in Haren (Table 3, subjects 19–36). They suffered from a variety of eye diseases: juvenile/congenital macular degeneration (4), age-related macular degeneration (2), albinism (4), optic atrophy (3), retinal vascular occlusion (1), and retinal degeneration (4). The visual acuity of the eye preferred for the telescope, as measured through the carrier glass, ranged from 0.25–0.45 (20/80–20/44; median = 0.30, first quartile = 0.25, third quartile = 0.30). Looking through the customized telescope, the range of the visual acuity increased to 0.55–1.10 (20/36–20/18; median = 0.79, first quartile = 0.71, third quartile = 0.79).

The mean actual gain in visual acuity due to the use of the telescope was $2.7 \pm 0.4\times$, range $2.2\times$ – $3.2\times$). Although, theoretically, a gain of better than $3\times$ is not possible for a $3\times$ magnifying telescope, these findings fall well within the test-retest variability for the ETDRS chart.[34] The visual acuity in the other eye ranged from 0.08–0.40 (20/250–20/50; median = 0.25, first quartile = 0.20, third quartile = 0.30).

Of our subjects, 12 preferred to view through the telescope with the dominant eye. For 2 of them this was the eye with the lower acuity. Six subjects chose to view through the telescope with the nondominant eye, with equal (2) or better acuity (4) compared with the dominant eye. Five subjects with increased glare sensitivity preferred the telescope to be mounted in carrier glasses with a light absorbing filter (subjects 21, 24, 30, 33, and 34).

None of these 18 subjects suffered from additional visual field defects, and their neuropsychological tests met the inclusion criteria. All had normal peak contrast sensitivity in the eye with the telescope, however, 3 subjects showed reduced peak contrast sensitivity in the fellow eye.

TABLE 2 **Characteristics of excluded subjects**

Nr	Age (year)	Gender	Driving licence	Driving experience	Eye disease category	Preferred eye for telecscope	VA without telescope	VA with clip-on telescope	Gain	Log (peak contrast sensitivity)	Visual field horizontal (deg)	Driving screening test	Passed assessment day	Reason for exclusion
1	34	f	y	3	A	OD	**0.15**	**0.40**	2.7	1.6	180	–	n	va + (vt)
2	21	f	n	0	G	OD	0.16	**0.49**	3.1	1.9	180	–	n	vt + (op)
3	73	f	e	3	B	OD	0.16	0.50	3.1	**1.5**	180	y	n	cs + (om)
4	20	m	n	1	A	OS	0.19	**0.45**	2.4	1.6	140	**n**	n	vt + (ds)
5	27	m	e	3	F	OS	0.19	**0.35**	1.8	1.6	–	y	n	vt
6	19	m	n	0	F	OD	0.20	**0.45**	2.3	1.6	–	**n**	n	vt + (np/om/ds)
7	81	m	e	3	B	OD	0.20	**0.40**	2.0	1.7	180	**n**	n	vt + (ds)
8	45	m	e	3	F	OS	0.20	**0.35**	1.8	**1.4**	140	y	n	vt + (cs/om/np)
9	40	f	y	3	D	OD	0.22	0.60	2.7	1.6	180	–	n	op
10	54	f	y	2	A	OD	0.25	0.85	3.4	**1.5**	160	y	n	oi + (cs)
11	81	m	e	3	B	OS	0.25	0.69	2.8	1.6	140	–	n	np
12	68	m	e	3	B	OD	0.30	0.89	3.0	1.6	160	**n**	n	ds + (np)
13	51	m	y	3	B	OD	0.32	0.72	2.3	1.6	**130**	–	n	vf + (np)
14	28	f	n	1	G	OD	0.39	1.26	3.2	**1.4**	180	–	n	cs + (np)
15	58	m	y	3	B	OS	0.40	1.00	2.5	1.6	180	**n**	n	ds + (np)
16	69	m	y	3	G	OS	0.48	0.79	1.6	**1.0**	**130**	y	n	oi + (cs + vf)
17	36	m	n	1	F	OS	0.35	0.89	2.5	1.9	155	y	y	oi
18	39	m	e	1	A	OD	0.39	0.89	2.3	1.9	150	y	y	oi

y = yes/positive, n = no/negative; – = not applicable; OD = right eye, OS = left eye. *Age* = age at date of assessment day. *gender*: m = male, f = female. *Driving licence*: e = driving licence expired. *Driving experience*: 0 = no driving experience, 1 = only lessons (<1.000 km), 2 = < 50.000, 3 = ≥ 50.000 km. *Eye disease*: A = juvenile/congenital macular degeneration, B = age-related macular degeneration, C = albinism, D = optic atrophy, E = retinal vascular occlusion, F = retinal degeneration, G = anomaly anterior segment. *VA* = visual acuity of preferred eye for the telescope. *Gain* = gain in visual acuity due to telescope. *Exclusion*: cs = contrast sensitivity, ds = driving screening on assessment day, np = neuro psychological, oi = own initiative, om = orientation & mobility screening, op = ophthalmic instable, va = visual acuity without telescope, vf = visual field; vt = visual acuity through clip-on telescope. Bold font indicates that the assessment result does not meet the inclusion criterion.

TABLE 3 **Clinical characteristics of included subjects**

Nr.	Age (year)	Gender	Eye disease category	Best eye	Dominant eye	Preferred eye for telescope	VA without telescope Preferred eye	VA with customized telescope Preferred eye	Gain	Log (peak contrast sensitivity) Eye with telescope	VA other eye	Log (peak contrast sensitivity) Other eye
19	18	m	C	OS	OS	OS	0.25	0.71	2.8	1.6	0.20	1.6
20	33	m	C	OD	OD	OD	0.25	0.79	3.2	1.6	0.20	1.6
21	21	m	C	=	OS	OD	0.25	0.55	2.2	1.8	0.25	1.8
22	23	f	C	OD	OS	OD	0.33	0.71	2.2	1.8	0.20	1.6
23	57	m	F	OS	OD	OD	0.30	0.65	2.2	1.6	0.40	1.4
24	32	m	D	=	OD	OD	0.28	0.89	3.2	1.9	0.28	1.9
25	35	m	F	OS	OD	OS	0.30	0.79	2.6	1.9	0.25	1.6
26	21	m	D	OD	OS	OD	0.25	0.71	2.8	1.9	0.16	1.8
27	72	f	B	OD	OD	OD	0.25	0.79	3.2	1.6	0.08	1.2
28	42	m	D	=	OD	OD	0.30	0.85	2.8	1.8	0.30	1.6
29	56	m	A	OS	OD	OD	0.35	0.79	2.3	1.6	0.40	1.7
30	34	m	B	OD	OD	OD	0.28	0.71	2.5	1.6	0.25	1.4
31	34	m	F	=	OD	OD	0.30	0.65	2.2	1.9	0.30	1.6
32	39	f	A	OS	OD	OS	0.30	0.79	2.6	1.6	0.25	1.6
33	65	m	E	OD	OD	OD	0.45	1.10	2.4	1.6	0.33	1.6
34	50	m	A	=	OD	OS	0.25	0.79	3.2	1.9	0.25	1.9
35	32	f	A	OD	OD	OD	0.30	0.89	3.0	1.6	0.25	1.6
36	24	m	F	=	OD	OD	0.33	0.76	2.3	1.9	0.35	2.2

OD = right eye, OS = left eye. *Age* = age at date of assessment day. *Gender*: m = male, f = female. *Eye disease*: A = juvenile/congenital macular degeneration, B = age-related macular degeneration, C = albinism, D = optic atrophy, E = retinal vascular occlusion, F = retinal degeneration, G = anomaly anterior segment. *Best eye* = eye with best visual acuity without telescope: "=" both eyes have equal acuity. *VA* = visual acuity (monocular). *Gain* = gain in visual acuity due to telescope.

TABLE 4 **Driving-related characteristics of included subjected**

Nr.	Driving licence	Driving experience	VA without telescope	VA with customized telescope	O&M training (hours)	Driving lessons (hours)	Judgement driving instructor	Number of CBR tests	Practical fitness to drive	Final conclusion
19	n	0	0.25	0.71	12	24	y	2	n	dp: unfit/bioptic use
20	n	0	0.25	0.79	12	22	y	2	n	dp: unfit/nervous
21	n	0	0.25	0.55	12	2	n	0	—	dl: unfit/driving aptitude
22	n	0	0.33	0.71	12	2	n	0	—	dl: unfit/driving aptitude
23	n	0	0.30	0.65	12	2	—	0	—	oi
24	n	0	0.28	0.89	14	36	y	2	n	dp: unfit/bioptic use
25	n	0	0.30	0.79	12	10	—	0	—	oi
26	n	1	0.25	0.71	12	10	y	1	n	dp: unfit/bioptic use
27	e	3	0.25	0.79	12	32	y	2	n	dp: unfit/nervous
28	n	1	0.30	0.85	12	36	y	2	y	dp: fit with bioptic
29	y	3	0.35	0.79	12	6	y	1	y	dp: fit with bioptic
30	y	3	0.28	0.71	12	6	y	1	y	dp: fit with bioptic
31	e	3	0.30	0.65	12	28	y	3	y	dp: fit with bioptic
32	e	3	0.30	0.79	15	20	y	1	y	dp: fit with bioptic
33	y	3	0.45	1.10	15	14	y	1	y	dp: fit with bioptic
34	e	3	0.25	0.79	15	12	y	1	y	dp: fit with bioptic
35	e	3	0.30	0.89	12	20	y	1	y	dp: fit with bioptic
36	y	3	0.33	0.76	12	6	y	1	y	dp: fit with bioptic

y = yes/positive, n = no/negative; – = not applicable. OD = right eye, OS = left eye. *Driving licence*: e = driving licence expired. *Driving experience*: 0 = no driving experience, 1 = only lessons (< 1.000 km), 2 = < 50.000, 3 = ≥ 50.000 km. *VA* = visual acuity. Final conclusion: dl = driving lesson/judgement driving instructor, dp = practical fitness to drive test/judgement CBR-official; oi = own initiative.

Predriving Training

The results with respect to the driving performance of the 18 subjects who passed the assessment day are summarized in Table 4. None of them experienced noticeable mobility, balance or orientation problems whilst using the bioptic, not even during the first attempt. In general, subjects were eager to learn how to use the bioptic in daily mobility situations. They all mastered the correct spotting technique for stationary and moving targets while standing still within 1 training session (3 hours). Fourteen of them finished the predriving training sessions within 4 weeks (12 hours). The other 4 subjects needed an additional session to optimize their viewing behavior with the bioptic during movement. The number of predriving training hours therefore varied between 12 and 15. Although the fourth training session contained a lot of revision exercises, the final evaluation of the predriving training indicated that <12 predriving training hours was insufficient.

Reading quickly with the aid of the bioptic appeared to be a difficult task. Spotting road signs that can be recognized at a glance was rarely a problem, but reading destinations or sub-signs without looking through the telescope for too long required specific training. Another difficult issue appeared to be the timing of spotting. Because of their reduced visual acuity, subjects were used to paying attention to road signs fairly late. The bioptic allowed them to read signs earlier, and the subjects had to be trained at what distance they could read a sign through the telescope with certainty. Furthermore, the selection of important objects and the selection of objects that have to be looked at through the bioptic were difficult tasks for the subjects.

None of the subjects were excluded on the basis of the predriving training or withdrew of their own accord during this phase of the project. All of the subjects practiced the use of the bioptic daily in their own environment and trained between 5–10 hours a week (not behind the wheel). In addition to general mobility, subjects used the bioptic for a wide variety of far and near vision tasks such as shopping, reading short texts, and close inspection of details. No incidents were reported during the training or the practice at home while using the bioptic.

Driving Lessons

Four subjects from our final group of 18 held a driving licence. The licences of 5 others had expired, and the remaining 9 subjects had never owned one. Two of this last group had taken driving lessons before and 3 had driving experience in vehicles not requiring a driving licence (tractor, electric car [maximum 16 km/h] and minicar [maximum 45 km/h]).

Despite the successful predriving training and the bioptic training as a passenger, subjects experienced a noticeable regression in their ability to use the bioptic as soon as they were behind the wheel. The combination of demanding traffic and the simultaneous use of the bioptic was experienced as a difficult task.

Because they showed insufficient aptitude for driving according to their driving instructor, 2 subjects with albinism (subjects 21 and 22) were rejected at an early stage of their driving lessons. Neither of them had prior driving experience. Their driving skill had not yet been screened during the assessment day, otherwise they would probably have been excluded at that stage of the project. In fact, this experience gave the initial impetus to introduce the driving screening test on the assessment day. Two others (subjects 23 and 25) withdrew of their own accord, 1 because a change of employment made the driving lessons too tiring, and the other because the anticipated expenses of the driving lessons were considered to be too high.

The remaining 14 participants showed progress in the course of the driving lessons resulting in safe driving and viewing behavior, as judged by the driving instructor. In this group, the number of driving lessons per subject varied between 6 and 36 (mean 19.4 $\pm$ 10.8). Not surprisingly, inexperienced drivers needed more lessons than the subjects who obtained a driving licence once, but they all succeeded in integrating the correct bioptic viewing behavior while driving, as judged by the driving instructor. Their global TRIP scores were "sufficient" and they were allowed to proceed to the official on-road test of practical fitness to drive.

In our project, the subjects only drove during daylight. Driving lessons took place during all seasons and varied weather conditions. Neither the subjects, the driving instructors, nor the CBR experts reported any particular inconvenience regarding the use of the bioptic during bad weather conditions.

Practical Fitness to Drive

Of the 14 subjects who were allowed to take the practical fitness to drive test, 7 drivers passed successfully the first time (global TRIP score "sufficient" and test result "fit when using the bioptic"). One subject was tested "unfit and denied retest" (subject 26). He had only very limited driving experience and had never held a driving licence. This subject was not allowed a reexamination, as he did not demonstrate accurate viewing behavior with the bioptic during the examination, and the CBR expert estimated that numerous lessons would be necessary for him to pass the practical fitness to drive test successfully.

The remaining 6 subjects were tested "unfit but allowed retest" and were allowed a second or third test of practical fitness to drive. Two of them passed that retest after additional lessons (subjects 28 and 31). In the beginning, they both had difficulty with using the bioptic adequately while driving. After specific attention was paid to the proper use of the bioptic for driving by the driving instructor, both viewing and driving performance gradually improved to a successful level. One of them (subject 28) was an inexperienced driver without a previous licence. He needed very specific driving and viewing instructions, but managed to pass the final test after 36 driving lessons. The other 4 subjects who were allowed a reexamination, were ultimately judged "unfit after retest." Two of them had albinism and showed insufficient steering performance, in particular, too much lateral swaying (subjects 19 and 20). For one of them (subject 20), bioptic viewing behavior was sufficient during the lessons according to the driving instructor, but nervousness played an important role in his failure. The other (subject 19) did not use the telescope often enough to anticipate oncoming traffic situations. The third subject who tested "unfit after retest" (subject 24) was also an inexperienced driver. Initially, he had problems integrating the use of the bioptic in the driving process. Once he started using the device at the repeated requests of the driving instructor, his driving performance began to improve. However, after 36 lessons his progress was not yet sufficient to pass the practical fitness to drive test. Both the driving instructor and the CBR expert felt that this subject stood a good chance of passing after an additional set of driving lessons, but the project management considered that this was beyond the scope of our demonstration project. The last subject who failed the retest was an experienced driver with reasonably good driving performance from the start of the driving lessons (subject 27). Although her bioptic viewing behavior was correct, she did not show sufficient progress in integrating it into her driving performance. Also, in her case, nervousness during the examinations might have played a role.

The most striking difference between successful and unsuccessful subjects was their previous driving experience. All but 1 of the 9 successful subjects who passed the practical fitness to drive test were experienced drivers. The total number of training hours (predriving + driving) for these successful subjects varied between 18 and 48 (mean 29.4 ± 10.6). By comparison, 6 of the 7 subjects who received a negative result from the driving instructors or the CBR experts were inexperienced drivers without a previous licence. For 3 of them, viewing behavior with the bioptic was mentioned as the decisive reason for rejection.

As can be seen in Tables 3 and 4, there is no indication of a relationship between the visual acuity, either with or without a telescope, and the outcome of the practical fitness to drive test. The same holds true for age, gender, eye disease, actual telescopic gain, hours of predriving training, and the number of driving lessons.

DISCUSSION

Subject Recruitment and Inclusion

It appeared that we had to include 36 subjects in order to end up with 9 subjects who passed the official test of practical fitness to drive. We do not exclude the possibility that the others can become proficient bioptic drivers, but this lies beyond the scope of our demonstration project, which only allowed a limited number of driving lessons.

Our project illustrates that each candidate under consideration for bioptic driving must be looked at individually, because a complex mix of psychological, optical, motor and behavioral issues, and driving experience is involved. One cannot rely solely on the information provided by the candidates themselves or their ophthalmologists, in combination with theoretical calculation of the visual acuity through the telescope. An individual approach is necessary to assess the actual visual functions with and without a bioptic, to examine the viewing performance in various conditions, and to assess practical fitness to drive.

Furthermore, a uniform information policy with regard to the public is imperative to prevent false expectations. To avoid mutual disappointment, we stress the importance of the motivation of possible bioptic drivers and a clear explanation of the perspectives to individuals eligible for bioptic driving, including an explanation of the risks of driving with low vision without professional guidance and information about alternative means of transport. Despite our extensive efforts to inform possible candidates about all the implications, 17% withdrew from the training program, which might have been prevented by an even better information process.

Because it was made abundantly clear to all applicants that participation could never lead directly to the permission to drive, motivation for participation was mainly based on the prospect that a positive outcome of the project might promote a change in the legal position. Considering this marginal personal benefit and the high individual effort and expenses involved, the relatively large number of 160 returned questionnaires can be seen as a sign of the importance of independent driving in our current society, even for visually impaired people.

Bioptic

Several models of spectacle-mounted bioptic telescopes are currently available.[22,34–36] Our Ocutech VES mini telescope has a fixed magnification of 3×. Subjects with a visual acuity worse than 0.16 (20/125) theoretically need more than 3× magnification to reach the limiting acuity value for driving of 0.5 (20/40). The higher the magnification, the more difficult it becomes to achieve a stable image during fixation[37] Nevertheless, in the United States, drivers sometimes use larger magnifications of up to 6×.[38] On the other hand, subjects with a relatively high visual acuity of close to 0.5 might actually prefer a telescope with a lower magnification. For this reason, our choice for a 3× telescope in this study must be considered a compromise. In future applications, we will consider a customized magnification, obviously on the condition of an optimal telescopic field of view.

As the bioptic is a rather expensive aid that users have to pay for themselves, we preferred to provide a versatile model. After discovering the benefits of the telescope during the predriving training, subjects appreciated the variable focus and used the bioptic in various daily situations for far as well as near vision.

Predriving Training

Both subjects and driving instructors reported that they considered training as essential to becoming acquainted with the correct use of a bioptic and to integrate the viewing behavior when driving.[16,39–45] Our predriving training was aimed at training the subjects to process all information continually, to decide which objects have to be inspected in more detail, to catch these objects within the field of the telescope instantly, and to read or distinguish the essential information quickly and without losing their overview. Although subjects experienced these tasks as very strenuous and fatiguing in the beginning, they all gradually mastered the technique and became accustomed to it in normal everyday mobility situations within 12–15 hours of training. This is comparable with the predriving training time suggested by Park and associates.[46] for inexperienced telescope users, but substantially less than the 55 hours of training time advised by Huss.[47,48] From discussions with the subjects, the driving instructors, and the CBR officials, the predriving training appears to function well, and we have no reason to expect that changing the predriving training would significantly improve the outcome in terms of practical fitness to drive.

Driving Lessons

Although all subjects mastered the correct bioptic viewing behavior before they started the driving lessons, the integration with driving was experienced as a difficult task. This was even true for the experienced drivers. It appears that bioptic viewing and driving are 2 complex tasks that do not integrate automatically when taught separately. There was no apparent difference in this process between younger and older drivers.

Albinism and Nystagmus

Of the subjects included, 4 had congenital albinism accompanied by nystagmus (subjects 19–22). During the first months of the project, the driving instructors and the CBR experts noticed that these subjects showed a marked swaying steering behavior while driving. Some driving experts recalled this behavior from earlier personal experience with applicants with nystagmus. Since the other project members were not aware of a relationship between lateral sway while driving and albinism or nystagmus, we did a literature search in the PubMed database (repeated on January 30, 2007) with the keywords "driving AND nystagmus" and "albinism AND driving." None of the 70 hits found showed any relationship between nystagmus and lateral sway during driving except in combination with alcohol abuse or use of medication. On the contrary, in the literature on bioptic driving, subjects with albinism are generally identified as ideal candidates.[41,49–54] In general, they have normal visual fields and contrast sensitivity, and as they have moderate-to-low vision from birth, most of them are used to the loss of visual acuity. The fact that all 4 subjects with albinism were beginner drivers might explain why they showed a larger amount of lateral sway than the experienced ones. The project management decided to exclude subjects with albinism and nystagmus from our demonstration project as this finding obviously lies beyond the scope of the current project. Further scientific research is needed to establish the role of nystagmus with respect to bioptic driving.

Practical Fitness to Drive

All successful subjects except one were experienced drivers and had previously owned a driving licence. Previous driving experience, while vision was still good, appears to be beneficial when learning to drive with a bioptic. From this it might be concluded that people with congenital forms of low vision are somewhat at a disadvantage compared with those with acquired loss of visual acuity. The driving experts indicated that a driving experience of 36 hours or less is relatively little for new drivers to demonstrate practical fitness to drive. To conform to the experts general experience, new drivers might need more lessons, but, taking into account the high costs and the uncertainty of a legal permit to drive, this was rejected by the project management. If bioptic driving becomes legally permitted in the Netherlands, further research is needed to design effective training methods for inexperienced drivers with reduced visual acuity.

We did not find a relationship between the visual acuity, either with or without the telescope, and the outcome of the practical fitness to drive test. However, only subjects with a visual acuity of 0.25 (20/80) or better appeared to progress to the driving phase of our demonstration project. As we used a very strict and selective inclusion protocol, it cannot be concluded from this study that subjects with a visual acuity worse than 0.25 are unable to drive with a bioptic telescope system.

Correct viewing behavior with the bioptic in general mobility situations is no guarantee of successful use of the bioptic during driving. Subjects reported that the integration of the acquired bioptic viewing behavior into the driving situation was a strenuous task that needed attention and training. During the course of the project, we learned that more attention had to be paid to the use of the bioptic and the integration of bioptic use for driving.

The project has been a learning exercise not only for the subjects, but also for the professionals. Each of the professionals involved is an expert on a particular part of the protocol, but none of them had practical experience with the use of a bioptic in driving. To succeed required comprehensive training, an interdisciplinary approach, an agreed protocol, conscientious documentation of the results, mutual exchange of knowledge, and an open discussion of specific findings.

A step-by-step evaluation of our protocol led us to the conclusion that none of the consecutive parts can be omitted as yet, and that each of the professionals plays an indispensable role. We have no apparent reason to change our original inclusion criteria at this time. In future, the assessment of viewing behavior with the bioptic after the predriving training may need to be objectified. If regulations are changed and bioptic driving becomes legal in the Netherlands, we urgently advise using a comparable protocol for testing candidates eligible for bioptic driving. In such a situation, subjects could be allowed more driving lessons if necessary, and one might consider using various types of telescope to meet individual needs even better. Before bioptic driving in dusky and dark situations is allowed, information is necessary about the use of the bioptic at night and whether this requires additional training and testing.

CONCLUSION

This is the first study in Europe to prescribe bioptic telescopes for driving and to train bioptic drivers. During the study, 18 subjects were successfully trained in the use of a bioptic telescope system in daily mobility situations. Of these, 9 passed the official on-road test of practical fitness to drive of the CBR, which is the official driving licensing authority in the Netherlands. This indicates that, after careful selection and training, safe and smooth bioptic driving is possible on an individual basis in Dutch traffic, and probably in the EU. We advocate legislation in the EU to allow people with moderately reduced visual acuity to demonstrate their practical fitness to drive by performing an individual on-road test conducted by the national official driving licensing authority. Currently, action is being taken with the responsible national authorities to regulate bioptic driving in the Netherlands. Balancing general traffic safety and individual freedom of mobility of people with reduced visual acuity is an important and complex issue. We advise an individually tailored interdisciplinary approach, in which the actual driving performance is considered.

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